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Lubrication

A Technical Publication Devoted to the Selection and Use of Lubricants

THIS ISSUE

Low Temperature Sludge in Automotive Gasoline Engines

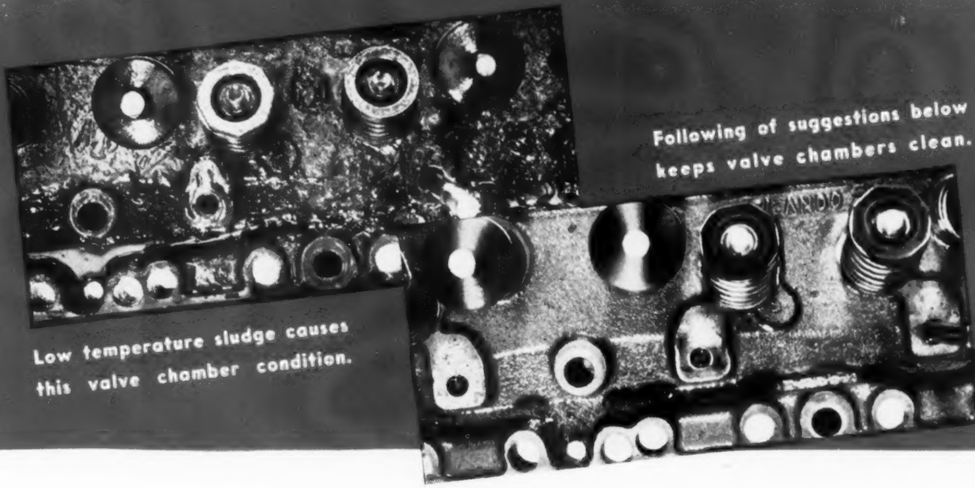
Further Studies

PUBLISHED BY
THE TEXAS COMPANY
TEXACO PETROLEUM PRODUCTS

HOW TO PREVENT

Low Temperature Sludge

IN FLEET OPERATIONS



Low temperature sludge causes this valve chamber condition.

Following of suggestions below keeps valve chambers clean.

LOW temperature sludge can be held to a minimum by following these recommendations:

- Use heavy-duty engine oil.
- Maintain jacket temperature at 160-180°F.
- Maintain crankcase oil temperature at approximately 180°F.
- Keep intake manifold temperature as high as possible consistent with freedom from intake manifold deposits.
- Change oil as frequently as possible consistent with allowable costs and maintenance schedules. Oil drains should be made while oil is hot after road operation.
- Employ best carburetor and air filter maintenance practices.
- Use the most viscous engine oil consistent with starting requirements and other operational factors.
- Use oil filter of adequate capacity and replace element at frequent intervals.
- Keep crankcase ventilation system clean, in operable condition and as warm as possible to alleviate stoppage due to freezing.
- Refrain from idling engine as much as possible particularly during cold weather.

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THE TEXAS COMPANY

LUBRICATION

A TECHNICAL PUBLICATION DEVOTED TO THE SELECTION AND USE OF LUBRICANTS

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Low Temperature Sludge in Automotive Gasoline Engines

Further Studies

THE general subject of low temperature sludge in automotive gasoline engines was discussed in the December, 1944 issue of Lubrication. Numerous advancements have been made since that time and it is the purpose of this article to present the latest developments on this subject.

THE problem of sludge in gasoline engines is almost as old as the engine itself. Two types of sludge have been recognized for many years; that associated with high temperature operation and attendant oxidation of the lubricating oil, and that associated with low temperature operation wherein the so-called mayonnaise or emulsion type deposit is developed. Although such difficulties have prevailed in automotive equipment for many years, restrictions imposed by wartime regulations along with inadequate maintenance personnel, shortage of replacement parts, heavier schedules, and other operational obstacles have collectively aggravated the formation of sludge and focussed attention on this problem.

Extensive investigations have been carried out toward minimizing engine deposits and oil oxidation occurring under high temperature operating conditions; solution through the use of heavy duty oils has been generally satisfactory. Low temperature operations have not received this comprehensive attention and thus many operators have suffered as a result of engine deposits from operating conditions normally considered to be mild. As will be discussed later, however, these "mild" conditions are actually more severe in some respects than many high temperature operations.

Laboratory engine tests have been developed to simulate low temperature service conditions and have been employed in a comprehensive study of the low temperature sludge problem. Much of the information to be presented subsequently has been obtained from these laboratory investigations. The operating conditions employed in this test procedure will be discussed later.

NATURE AND METHOD OF FORMATION

Deposit Analyses

It is often difficult to determine the cause of engine deposits from their analyses alone since most service operations involve both low and high temperature conditions.

Examination of deposits from laboratory engines known to have operated exclusively under low temperature conditions shows that on an oil-free basis they are composed primarily of fuel diluent, water and free mineral matter (lead compounds from fuel combustion, and iron and other metals occasioned by engine wear and rusting), along with lesser quantities of carbonaceous material and oxidation

products. An analysis of such deposits is shown in Table I along with similar analysis from service operations. The latter case demonstrates the difficulty of identifying low temperature deposits and recommending corrective measures on the basis of deposit analysis alone. This is due to the fact that most service operations are conducted with high temperatures prevailing during some portion of the operation, thereby baking existing deposits and supplementing them with oil oxidation products.

Used Oil Characteristics

Used oil from both low and high temperature operation often exhibits a high neutralization number. In the first case oil deterioration is negligible and the high neutralization number is associated with the oil insolubles originating from the combustion chamber; in the latter case, the high neutralization number results from oxidation of the lubricating oil.

Extended low temperature operation is reflected in unusual characteristics of the used oil which differ from those resulting from high temperature operation as shown in Table II. In the case of low temperature operation, it will be noted that the neutralization number is relatively high, thus suggesting that extensive oil oxidation had occurred. However, from exhaustive laboratory tests, it is known that negligible oil deterioration occurs at the low temperatures employed (as evidenced by low percentage of oil soluble oxidation products) indicating that the high neutralization number resulted from material originating from some other source. The amount of oil insolubles, consisting of incomplete combustion residues, is also high. After clarification (removal of insolubles) the neutralization number is greatly decreased, indicating that the material responsible for this high value is associated with these insolubles. This is further substantiated by the very high neutralization number of the insolubles, themselves.

In the case of high temperature operation, it will be noted that the neutralization number is also high. Since the oil soluble oxidation products have a very high neutralization number and are present in large quantity it is evident that most of the material contributing to the high neutralization number originates from oxidation of the lubricating oil. Removal of the oil insolubles, which are present in minor quantities, by clarification reduces the neutralization number only slightly, it remaining relatively high due to the presence of the soluble oxidation products.

The foregoing discussion is demonstrated by Figure I, which shows that for low temperature operation, the neutralization number is associated with oil insolubles originating from combustion residues,

TABLE I
TYPICAL ENGINE DEPOSIT ANALYSES

Deposit Components (Oil-free basis)	*Average from Low Temperature Laboratory Engine Tests*	*Typical Field Sample*
Diluent, %	20.3	14.8
Water, %	51.5	9.1
Oxidation Products, %	8.2	34.2
Free Carbon and Carbonaceous, %	3.7	21.7
Free Mineral Matter, %	16.3	20.2
Total %	100.0	100.0

TABLE II
TYPICAL USED OIL ANALYSES

	New Oil	*Following Low Temperature Operation* — *As Drained*	*Following Low Temperature Operation* — *After Clarification*	*Following High Temperature Operation* — *As Drained*	*Following High Temperature Operation* — *After Clarification*
Neutralization Number	0.06	4.7	1.2	5.2	3.9
Dilution, %	0	15.8	15.8	0	0
Oil Insolubles, %	0	2.07	0	1.16	0
Oil Soluble Oxidation Products, %	0	0.20	0.20	3.09	3.09
Neut. No. on Oil Insolubles	..	17.2	..	28.8	..
Neut. No. on Sol. Ox. Prod.	..	..*	..*	63.2	63.2

*Quantity of oxidation products insufficient for analysis.

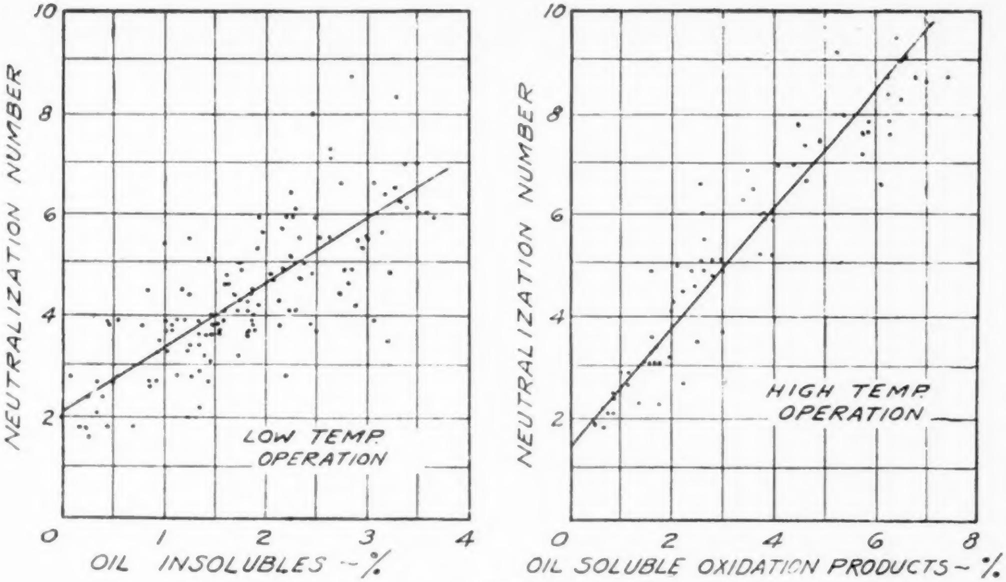

Figure 1—Relation of used oil characteristics.

while for high temperature operation, it is associated with oil soluble oxidation products resulting from deterioration of the lubricating oil itself.

Additional information in regard to origin and distribution of the neutralizable material causing the neutralization number in used oil is shown in Table III. It is apparent that in the case of low temperature operation a majority of the material is water soluble, indicating it to be of low molecular weight and evidently originating from the fuel. With high temperature operation, however, the material is largely water insoluble indicating high molecular weight with oil oxidation as its source.

It is significant that the nature of the neutralizable materials formed in low temperature operation has not been found corrosive to "alloy" bearings while in high temperature service, these materials are generally corrosive.

Engine Deposits vs. Oil Insolubles

The amount of oil insoluble materials produced with a given fuel under any set of low temperature operating conditions is approximately constant. The relative amount of these materials deposited on the engine parts or remaining in the oil, to be drained at the oil change period, depends upon the ability of the oil to retain them in suspension.

It was previously pointed out that with low temperature operation, contaminants from the combustion chamber evidence themselves as insoluble material in the lubricating oil and as deposits on various engine parts. Experience has shown that most of the deposits accumulate in the oil pan and valve compartments; oil ring and piston skirt deposits are small in comparison. The latter, however, are considered to be very important since they contribute directly to poor oil control, spark plug fouling and piston seizure.

It is not difficult to determine quantitatively deposits present on piston skirts, in oil rings and on oil pan and cover plate surfaces. In fact, such determinations are made on nearly all laboratory engine tests. Figure 2 is a plot of results from low temperature laboratory engine tests showing the relationships between oil insolubles and the above mentioned deposits which are normally measured. It

TABLE III

DISTRIBUTION OF NEUTRALIZABLE MATERIAL IN USED OIL

Per cent of Total Neutralizable Material Soluble in:	*Low Temperature Operation*	*High Temperature Operation*
Diluent	5	0
Water	58	17
Residual Oil*	37	83

*Diluent and water-free but containing insolubles and soluble oxidation products.

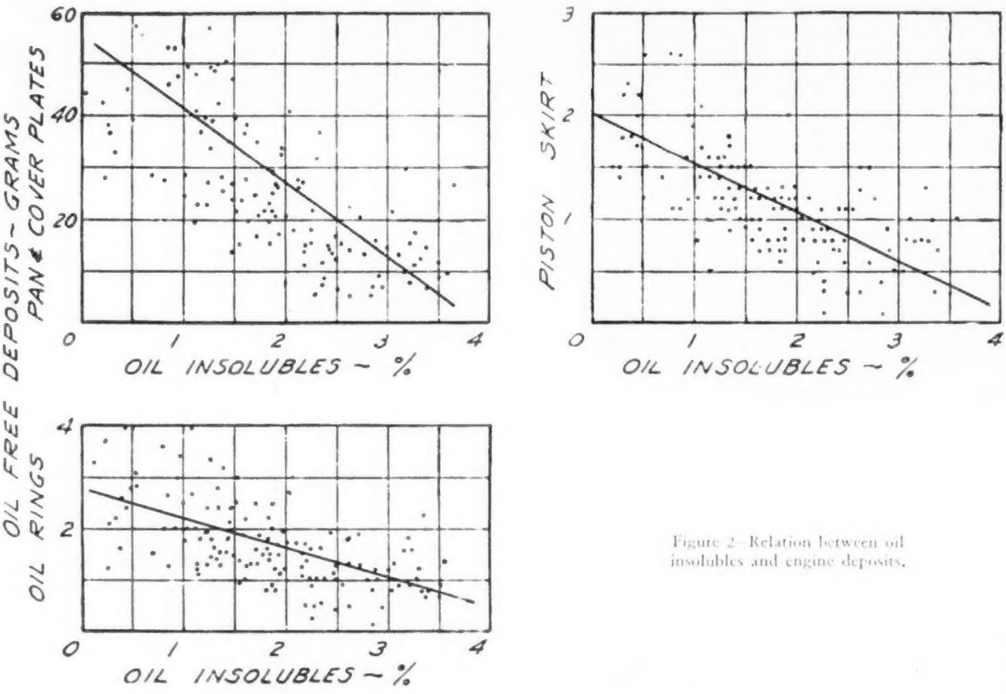

Figure 2—Relation between oil insolubles and engine deposits.

will be noted that as oil insolubles increase engine deposits decrease. From the intercepts of these curves it appears that when engine deposits become zero, so that all contaminants are in the oil, an oil insoluble content somewhere between 3.9 and 4.8% (average 4.3%) would result. Basis this average value and a normal oil drain of 4 quarts (3178 grams), an average total oil insoluble content of 137 grams is determined. As a check on this line of reasoning, ten runs were made and deposits carefully determined for all engine parts. Average results of these tests are shown in Table IV, compared with values predicted from Figure 2 as outlined above; the agreement is remarkably good.

Corrective Measures

Low temperature sludge can be alleviated by employing heavy-duty oils and by altering operating techniques.

It is evident from the foregoing discussion that low temperature sludge is largely the result of contaminating the lubricating oil with extraneous matter originating from incomplete combustion of the fuel oxidation products. Since the oil itself is not oxidized or otherwise altered to any appreciable extent, it is not responsible for originating such deposits. It is evident at present that two practical means of alleviating the difficulty present them-

TABLE IV
DISTRIBUTION OF ENGINE DEPOSITS

	Predicted From Figure 2	*Average of 10 Runs*
Oil Insolubles, per cent	1.72	1.72
Total Oil Insolubles, grams	54.8*	57.4
Piston Skirt Deposits, grams	1.2	1.3
Oil Ring Deposits, grams	1.8	1.7
Oil Pan and Cover Plate Deposits, grams	31.0	27.8
Block, Valve Compartment and All Other Parts Deposits, grams	48.2**	38.3
Total Engine Deposits + Oil Insolubles, grams	137.0	126.5

*Basis 4 quarts (3178 grams) oil drained $\frac{3178 \times 1.72}{100} = 54.8$.

**By difference.

TABLE V
COMPARISON OF SERVICE AND LABORATORY TESTS

Deposit Components (Oil-free Basis)	*Average for Vehicles*	*Average from Laboratory Engine Tests*
Diluent, %	25.4	20.3
Water, %	32.4	51.5
Oxidation Products, %	5.4	8.2
Free Carbon and Carbonaceous, %	9.2	3.7
Free Mineral Matter, %	27.6	16.3
Total %	100.0	100.0
Used Oil Analyses	*Average for Vehicles (2000-Mile Basis)*	*Average from 2000-Mile Laboratory Engine Tests*
Neutralization Number	2.7	4.2
Dilution, %	10.7	17.1
Oil Insolubles, %	2.06	1.99
Oil Soluble Oxidation Products, %	0.15	0.21

selves, and to obtain best results, both should be employed.

1. Use lubricating oils which are capable of keeping contaminants in finely divided suspension rather than permitting them to be deposited on engine parts.

2. Alter operating techniques thereby minimizing the formation of these contaminants.

An extensive program of laboratory engine tests covering fuels, lubricating oils and operating variables, was conducted to substantiate the concepts presented above.

LABORATORY ENGINE TESTS

Operating Conditions

The operating conditions employed in this accelerated laboratory test were developed to simulate in only 40 hours (2000 miles) of engine operation the results from a fleet of 35 passenger cars and trucks operated for a long period in service known to be predominantly low temperature. Table V compares the results of engine deposit and used oil analyses from this fleet and from the laboratory engine tests. It is evident that the results are similar, although the laboratory test is more severe.

The basic test conditions are outlined in Table VI: regular grade motor fuel containing the maximum permissible amount of tetraethyl lead was used. Constant engine performance is insured throughout each series of tests by employing reference runs, under the conditions outlined, before and after each test run; results of test runs are compared with these reference runs.

Evaluation of Test Results

Comparisons are accomplished by weighing piston skirt, oil ring and pan and cover plate deposits and rating those from the test run on the basis of an

TABLE VI
LABORATORY ENGINE TEST CONDITIONS

Engine	1942 Chevrolet
Fuel	Regular grade. Maximum TEL
Oil	SAE 20, 95 VI, Straight Mineral
Speed, rpm	2500
Load, BHP	45
Jacket Temperature, °F.	95
Crankcase Oil Temperature, °F.	155
Intake Manifold Temperature, °F.	95
Ambient Temperature, °F.	Room (aver. 90° F.)
Crankcase Ventilation, cu. ft. air/min.	1.0
Air-Fuel Ratio	14.5
Test Duration, hours	40 (2000 miles)
Oil Changes	None
Oil Filter	None

Figure 3—Piston from typical laboratory engine low temperature reference run.

assigned value of 100 for the average of the two reference runs. For example, assume that piston skirt deposits from a test run amount to 0.7 grams and the average from preceding and succeeding reference runs is 1.4 grams, then the piston deposit rating for the test run is $\frac{0.7}{1.4} \times 100 = 50$.

In addition to such comparisons, photographs of various engine parts are taken for each run. Figures 3, 5 and 6 show the dirty condition of engine parts following a typical reference run, while Figure 4, 7 and 8 show similar parts following a test run demonstrating the vastly improved performance which can be obtained by simple operational changes.

Test Results

Results of investigations to alleviate low temperature sludge through modifications in fuel, lubricating oil and operating conditions are summarized in Table VII. These modifications will be discussed separately below and considered with respect to their service application.

Fuel

Inasmuch as low temperature deposits are associated with incomplete combustion of oxidation products originating from the fuel, which are thought to form resinous material insoluble in the oil, it follows that the fuel employed should have some bearing on the formation of such deposits. The part played by fuels in this connection is currently under investigation. With the incomplete information available and the problem still far from solution, it is not possible to draw conclusions or make practical recommendations at the present time.

Lubricating Oils

Heavy-duty oils will reduce engine deposits in some respects, however, they do not comprise a complete solution.

Since lubricating oils of the heavy-duty type possess the ability to retain insoluble matter in suspension, they would be expected to show a reduction in low temperature sludge formation. The data in Table VII indicate that use of these oils, although not a complete solution to the problem, results in improved performance, particularly in regard to reduction of oil ring, oil pan and cover plate deposits.

Jacket Temperature

Operating jacket temperatures in the 160-180°F. range should be maintained at all times. Where engines are idled overnight, jacket temperatures should also be maintained in this range if possible. Better still, operations would be improved by not idling at all.

Tests made under the regular conditions outlined in Table VI at jacket temperatures from 95 to 180°F. demonstrate that increasing jacket temperature to 120°F. results in considerable improvement; further increase to 180°F. results in a still greater reduction in engine deposits.

Further runs were conducted in a cold room at 0°F. with the engine idled for 40 hours thereby simulating the winter practice employed by some operators to idle their engines overnight when

Figure 4—Piston from laboratory engine test run using improved operating conditions.

TABLE VII

RESULTS OF LABORATORY ENGINE LOW TEMPERATURE SLUDGE TESTS

Phase of Investigation	*Relative Deposit Weight, %* Piston Skirts	Oil Rings	Oil Pan and Cover Plates
Lubricating Oil			
Straight Mineral (reference)	100	100	100
Heavy Duty (A)	81	37	56
Heavy Duty (B)	88	43	19
Jacket Temperature (regular test, 90° F. aver. ambient)			
95° F. (reference)	100	100	100
120	68	33	66
180	51	35	28
Jacket Temperature (500 rpm idle, 0° F. ambient)			
80° F. (reference)	Trace	Trace	100
120	Trace	Trace	9
160	Trace	Trace	19
Crankcase Oil Temperature			
155° F. (reference)	100	100	100
180	82	53	67
225	180	58	192
265	88	94	45
Intake Manifold Temperature			
70° F.	101	133	250
95 (reference)	100	100	100
160	55	50	77
190	44	41	58
Air-Fuel Ratio			
18.2:1	130	68	150
14.5 (reference)	100	100	100
10.5	74	6	13
Lubricating Oil Viscosity			
SAE 10	100	83	112
" 20 (reference)	100	100	100
" 30	76	41	56
" 50	52	31	37
Oil Change Period			
40 hours (reference)	100	100	100
10 "	58	72	53
5 "	34	....	22
2.5 "	15		13
Oil Filter (cotton waste, full flow, large capacity)			
None (reference)	100	100	100
Case without element	62	79	39
Complete with element (no changes)	54	68	16
Oil Filter (cotton waste, by-pass)			
None (reference)	100	100	100
No element changes	87	99	104
Element change at 20 hours	136	84	41
Crankcase Ventilation			
1 cfm (reference)	100	100	100
3 "	121	77	55
1 " reversed flow	139	110	109
3 " reversed flow	111	137	88
Diluent and Water Extractor			
None (reference)	100	100	100
Extractor with 5 qts./hr. oil flow	116	137	250
Extractor with 25 qts./hr. oil flow	92	137	50
Improved Operating Conditions			
None (reference)	100	100	100
With conditions changed from those in Table VI in following respects	18	11	10
Oil—Heavy Duty (SAE 20)			
Jacket Temperature—160° F.			
Crankcase Oil Temp.—180° F.			
Intake Manifold Temp.—150° F.			
Oil Changes—20 Hours			
Oil Filter—Yes			
Oil Filter Element Changes—20 hours			

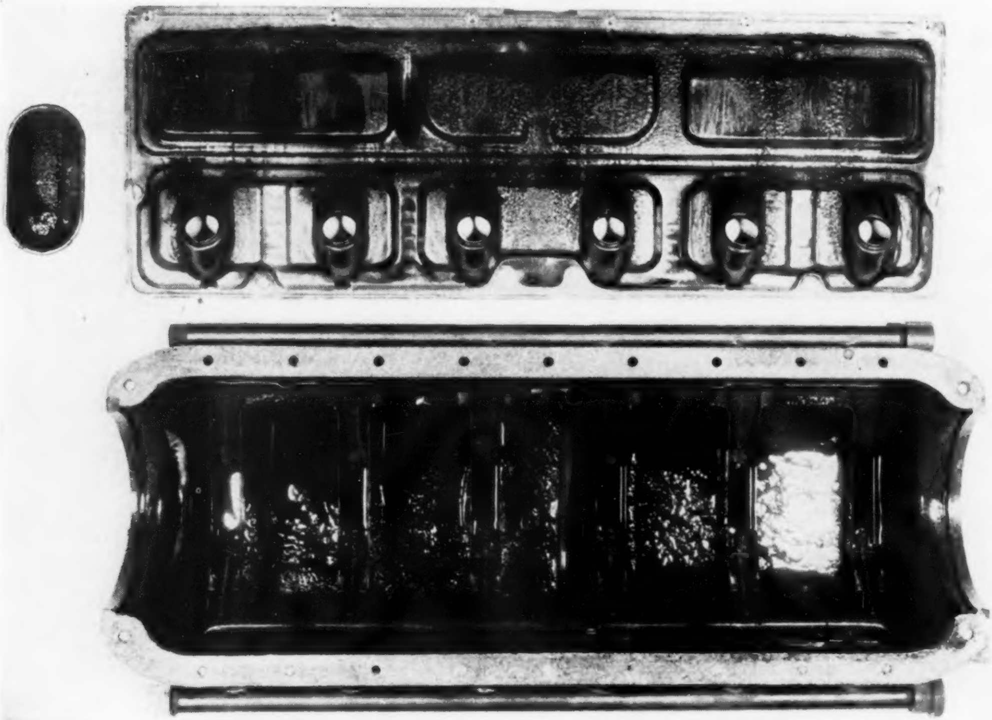

Figure 5—Oil pan, push rod cover and oil pump screen from typical laboratory engine low temperature reference run.

stored outdoors. Jacket temperature was varied from 80 to 160°F. with results paralleling those mentioned above. Throughout these runs a crankcase oil temperature of approximately 90° F. was observed. In this case, an increase in jacket temperature to 120° F. or above largely eliminated the deposits obtained at 80°F. It will be noted that this operation produced only pan and cover plate deposits; pistons and oil rings were substantially clean, apparently due to their low temperature and the washing action of the excessive diluent present. However, even under the most favorable conditions investigated considerable dilution and oil contamination occurred and upon subsequent road operation these materials would undoubtedly lead to further deposit formation.

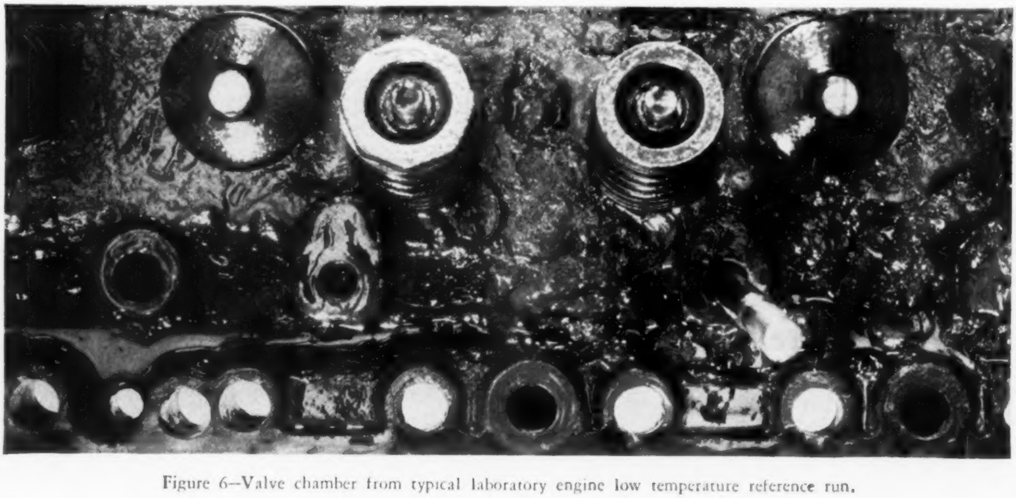

Figure 6—Valve chamber from typical laboratory engine low temperature reference run.

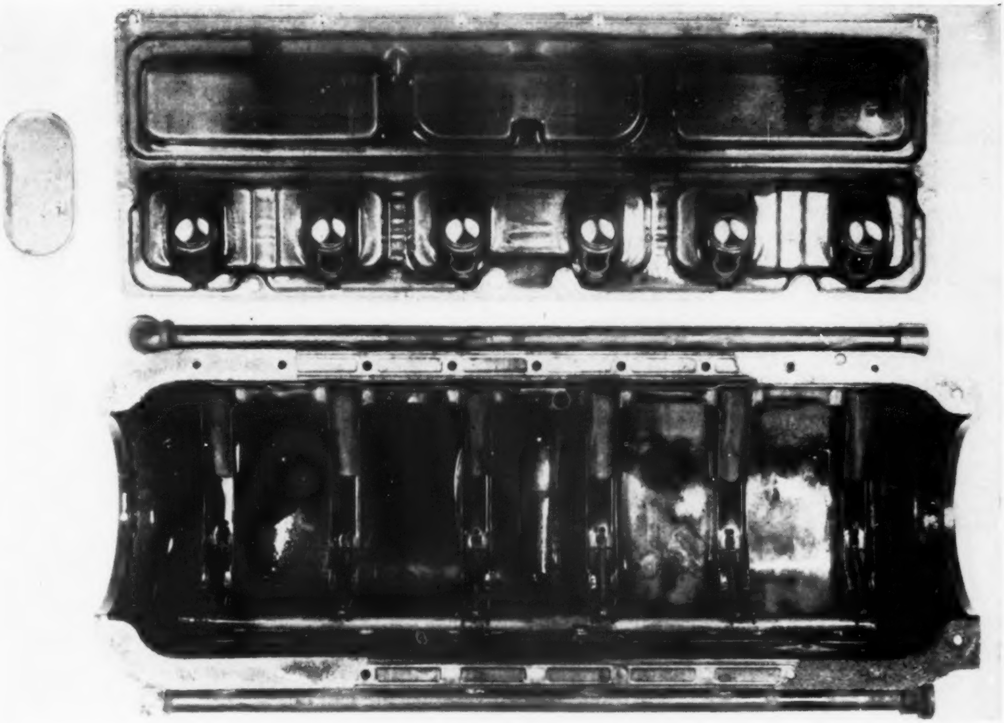

Figure 7—Oil pan, push rod cover and oil pump screen from laboratory engine test run using improved operating conditions.

Crankcase Oil Temperature

Crankcase oil temperature should be maintained at approximately 180°F. in order to minimize deposits. Temperatures above or below this value appear to aggravate engine deposits.

An increase in crankcase oil temperature from 155 to 180°F. results in a significant improvement in operation, particularly in regard to reduction of oil ring and pan and cover plate deposits. With further raising of oil temperature to 225°F., a general increase in deposits is observed over those obtained at 155 and 180°F. This is due to the fact that at this oil temperature the deposits are composed of both high and low temperature materials, thereby producing a combined effect resulting in a dirtier engine. At 265°F. an analogous situation

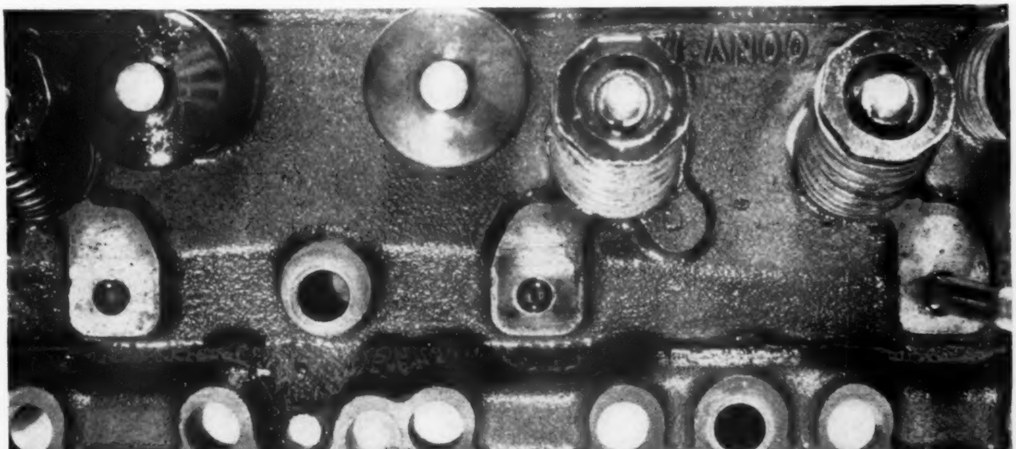

Figure 8—Valve chamber from laboratory engine test run using improved operating conditions.

Figure 9—Frozen condition of breather pipe resulting from engine idling in cold room at zero °F.

exists except that in this case low temperature materials are minimized with resultant reduction in deposits from those obtained at 225°F.

Intake Manifold Temperature

Intake manifold temperature should be maintained at the highest value possible consistent with freedom from manifold deposits.

Since engine deposits are associated with poor combustion of the fuel, any measures taken to improve combustion (such as increasing intake mixture temperature) would be expected to improve performance. Intake mixture temperatures from 70 to 190°F. were investigated. It will be observed in Table VII that increasing intake manifold temperature results in a consistent and substantial reduction in the engine deposits measured. It is of interest to note that at manifold temperatures of 160° F. and higher, carbon-like deposits were observed in the intake manifold.

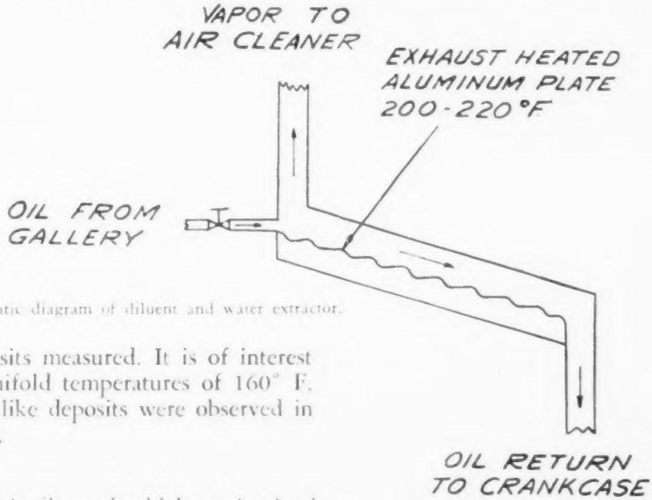

Figure 10—Schematic diagram of diluent and water extractor.

Air-Fuel Ratio

Carburetors and air filters should be maintained in good condition by conforming to best service practices.

Since air-fuel ratio is known to alter combustion it should be expected that changes in air-fuel ratio would influence low temperature engine deposits. Tests were conducted at air-fuel ratios ranging from a lean value of 18.2:1 to a rich value of 10.5:1. In the case of lean mixtures, deposits are generally increased over those obtained at normal mixtures, possibly due to intermediate combustion products with this slower burning mixture and the presence of excess air. With rich mixtures engine deposits are greatly reduced. Since extensive fuel dilution occurs with such mixtures the reduction of deposits is apparently associated with the washing action of the diluent as well as with possible changes in combustion occasioned by a deficiency of air.

In actual service rich mixtures are not very practical because of fuel economy, while lean mixtures lead to detonation and preignition with their attendant serious difficulties. It thus appears that alleviation of the low temperature sludge problem through carburetion is not feasible. However, carburetion equipment should be maintained in good condition.

Lubricating Oil Viscosity

The most viscous lubricating oil consistent with starting requirements and other factors should be used.

Although a wide choice in oil viscosity is not always possible due to starting limitations and other factors, it was considered desirable to ascertain the effect of viscosity on engine deposits. Tests were conducted on lubricating oils ranging from SAE 10 to 50. The data in Table VII indicate that a consistent improvement is realized with increased viscosity. It is possible that the more viscous oils may contribute to improved performance through improved piston-cylinder seal. However, improvement is primarily a result of the ability of the heavier oils to hold more contaminants in suspension to be drained with the used oil rather than deposited throughout the engine. This characteristic is indicated by the following data obtained on the used oil from these tests.

SAE Grade	*Oil Insolubles, %*
10	0.87
20	1.27
30	1.50
50	2.66

Oil Change Period

All efforts should be made to change oil as frequently as possible consistent with allowable costs and maintenance schedules.

Previous discussion pointed out that under low temperature conditions negligible oil oxidation occurs and contaminants are present largely as oil insolubles. If these materials were frequently re-

moved, improved performance should result. Accordingly, tests were conducted varying oil drains from the normal 40 hours (2000 miles) to as low as $2\frac{1}{2}$ hours (125 miles). It is evident from data in Table VII that there is a marked reduction in engine deposits with more frequent oil changes.

Oil Filter

Reduction of engine deposits can be obtained by the use of an efficient full flow filter. However, the standard by-pass type is effective provided frequent element changes are employed.

Further tests in regard to efficient removal of oil contaminants were carried out with a full flow filter whereby all of the oil leaving the pump is passed through the unit before reaching the engine. In view of the large capacity of this filter (3 gallons) the extra oil required was considered by conducting tests using the filter case alone. The results shown in Table VII indicate some improvement in performance due to the additional oil and some additional improvement with the complete unit.

Although efficient filtration of the oil greatly reduced engine deposits, full flow filters are generally considered to be impractical in service. Accordingly, tests were made with a regular size filter operating on the normal by-pass principle. Results indicate that without element change during the entire 40-hour period, little if any improvement in engine condition results. However, with the element changed at 20 hours, improvement is realized, with respect to oil pan and cover plate deposits. No reasonable explanation is available to account for the increased piston deposits.

Crankcase Ventilation

Every effort should be made to keep the crankcase ventilation system clean, in operable condition and as warm as possible to alleviate stoppage due to freezing. Changes in crankcase ventilation are sometimes desirable. However, any alteration in the normal arrangement should be undertaken with great caution.

It was previously explained that engine deposits are associated with combustion contaminants consisting of water, fuel diluent and insoluble matter. Since some of the diluent and water vapor can be removed by crankcase ventilation, tests were conducted to investigate the effect of such ventilation on engine deposits.

Crankcase ventilation in the laboratory test engine is normally from the overhead valve compartment downward with exit from the crankcase breather pipe. With normal test conditions, air is metered through this system at the rate of 1 cu. ft./min. thereby simulating road service. It will be observed in Table VII that an increase in crankcase ventilation from 1 to 3 cu. ft/min. reduces deposits to some extent, on the oil rings and pan and cover plates. In similar tests with the direction of air flow reversed, heavy engine deposits are experienced.

One further point which is usually not recognized in service operation is the possibility of breather system freezing. Figure 9 shows the condition of the breather system following one of the cold room tests mentioned previously. The system in this case was rendered completely inoperative due to accumulation of "snow" in the breather pipe. Note also the ice formation below the breather outlet.

Diluent and Water Extractor

Further investigations in regard to water and fuel diluent removal were conducted with the laboratory unit shown in Figure 10 designed to remove these materials from the crankcase oil during engine operation. From Table VII it appears that with sufficiently high oil flow some improvement in oil pan and cover plate deposits may be obtained.

Devices of this nature are reported to be beneficial in some operations; their merits should be carefully determined for the particular service involved.

Improved Operating Conditions

Marked reduction in engine deposits can be realized through employing heavy duty oil, high engine temperatures, frequent oil changes and a suitable oil filter with frequent element replacements.

From the foregoing discussions it is evident that low temperature deposits can be alleviated to some extent by changes in oil, fuel and various operating conditions. As an overall test of *some* of these corrective measures, a run was made with the standard conditions outlined in Table VI modified as indicated in Table VII. The results shown therein demonstrate the effectiveness of the alterations investigated. The engine was substantially clean at the conclusion of the run, as evidenced by Figures 4, 7 and 8. Employment of other aids such as increased oil viscosity, and better crankcase ventilation are additional possibilities for still further deposit reduction.

CONCLUSION

Great strides are being made towards overcoming the problem of low temperature sludge not only by the petroleum industry but by the engine manufacturers and fleet operators as well. With the knowledge that this type of sludge is not caused by the engine lubricating oil, engine manufacturers are giving careful consideration to the design of their new engines. Fleet operators are accepting the responsibility imposed by the maintenance and control of mechanical and operating variables affecting this condition. Through these combined efforts everyone is benefitting.

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